Fundamentals of GIS

Emphasizing GIS Use for Natural Resource Management

BSRSI

Produced for:

Basic Science and Remote Sensing Initiative

Department of Geography

Michigan State University

FUNDAMENTALS OF GIS

EMPHASIZING GIS USE FOR NATURAL RESOURCE MANAGEMENT

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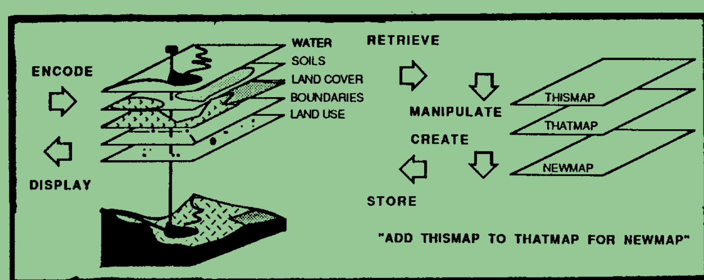
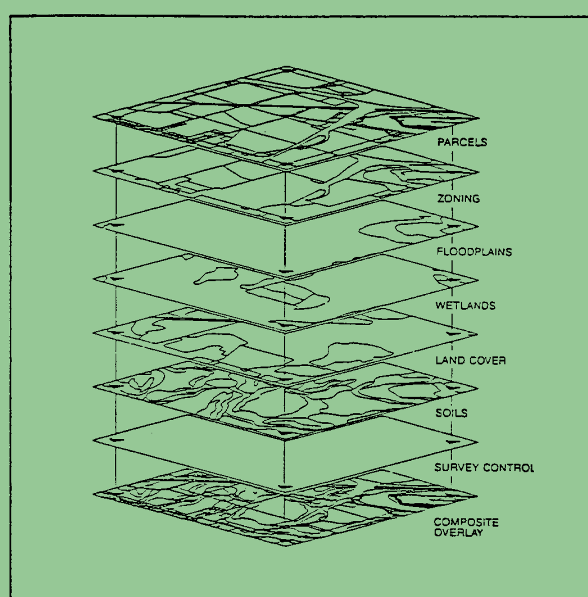




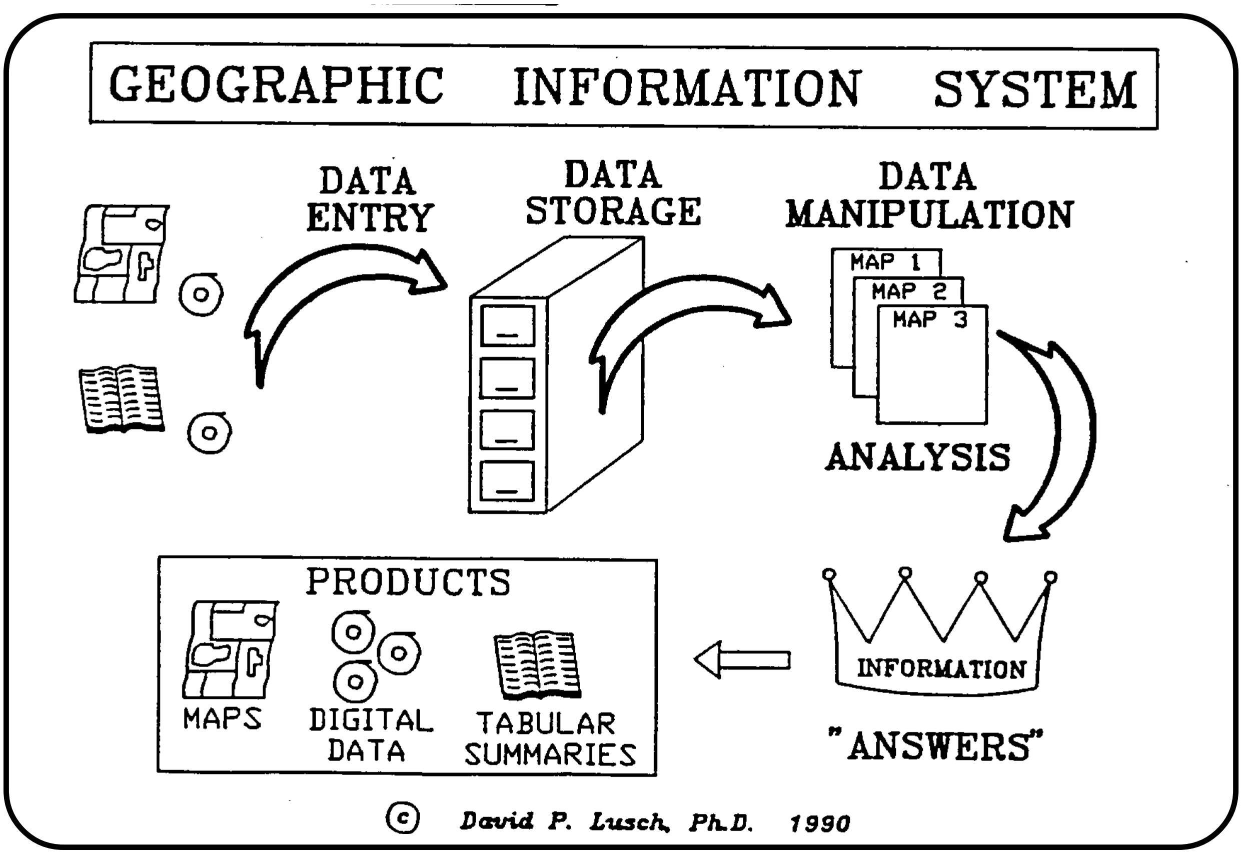
November, 1999

OVERVIEW OF GIS

G I S

Geographic Information Systems

An INTEGRATED SYSTEM of COMPUTER HARDWARE and SOFTWARE coupled with ***PROCEDURES*** and a ***HUMAN ANALYST*** which together support the CAPTURE, MANAGEMENT, MANIPULATION, **ANALYSIS**, **MODELLING**, and DISPLAY of SPATIALLY REFERENCED DATA



G I S Capabilities:

❑ QUERY FOR LOCATION

"Show me all the countries of South America that have a population greater than 20,000,000. "

❑ QUERY FOR CONDITION

"Display the population of each country I point to on the map."

❑ TREND ANALYSIS

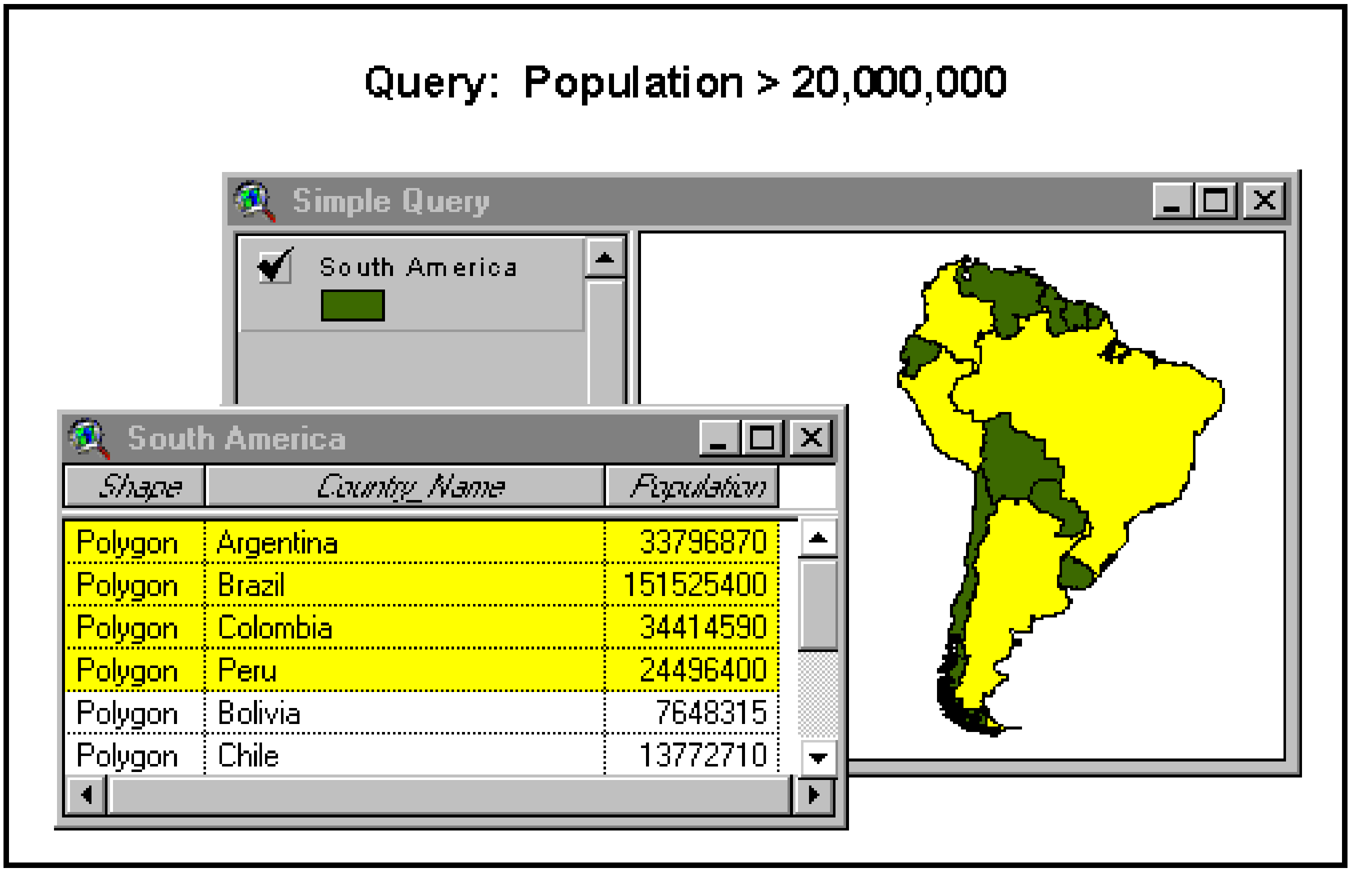
"Show me where the census blocks are that have experienced more than a 50% population change between 1980 and 1990."

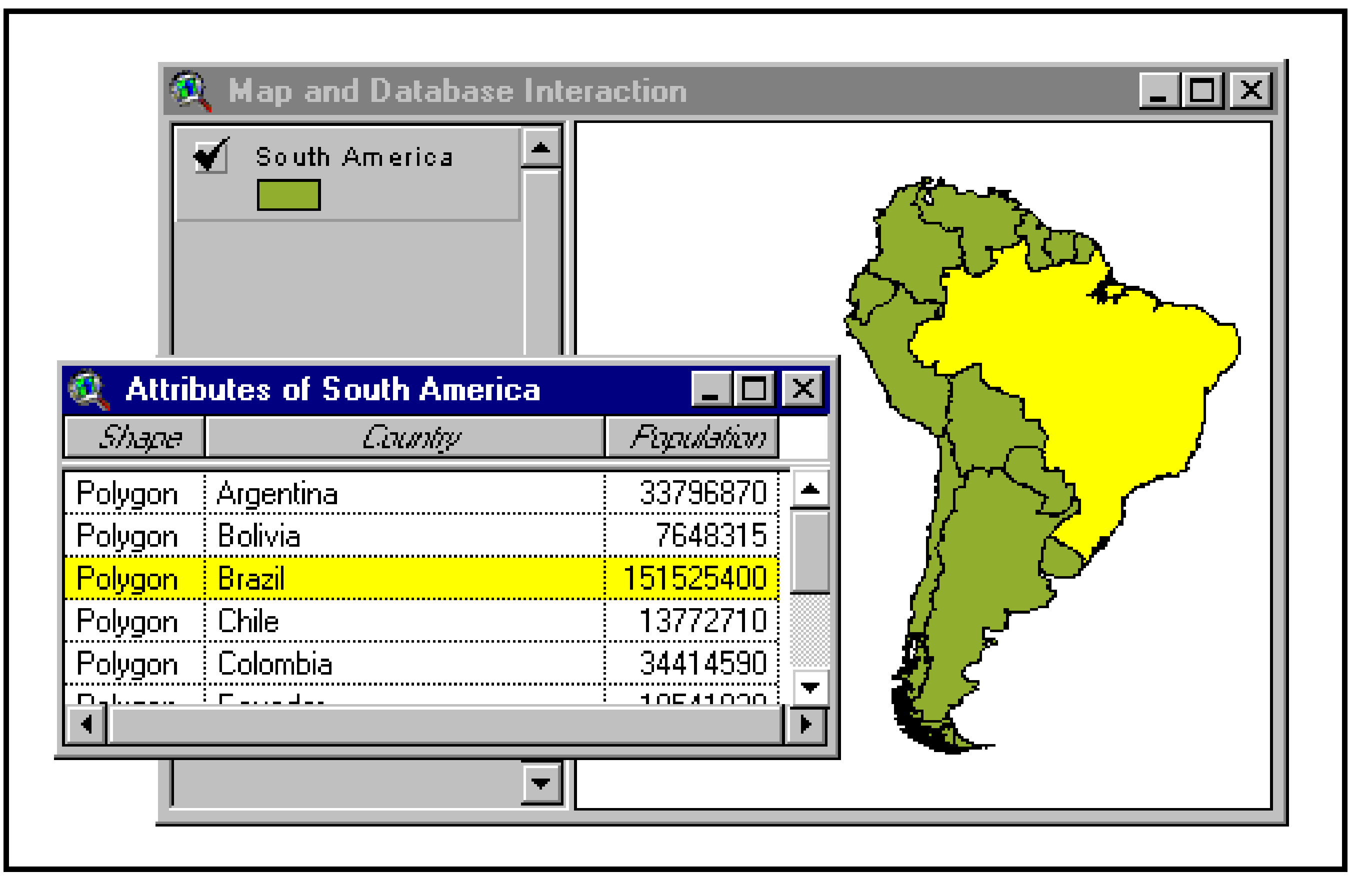
❑ PATTERNS ANALYSIS

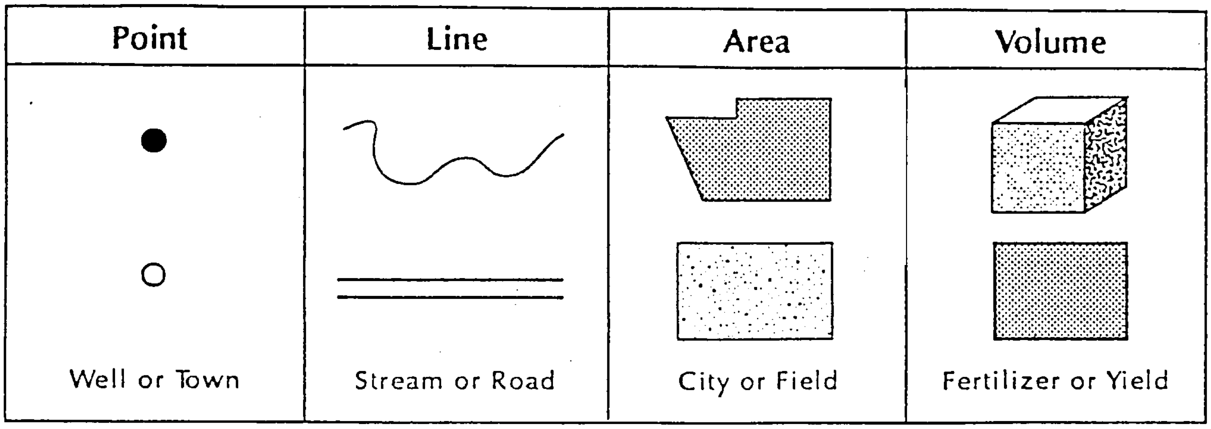
"Calculate the fragmentation index for all the forest patches in the municipio."

❑ MODELLING

"Which route for the new highway has the lowest cost in terms of losses of housing, prime farmland, and wetlands, while minimizing the needs for cutting and filling."


Query: Population > 20,000,000
Simple Query
South America
South America
Shape
Country_Name
Population
Polygon Argentina 33796870
Polygon Brazil 151525400
Polygon Colombia 34414590
Polygon Peru 24496400
Polygon Bolivia 7648315
Polygon Chile 13772710

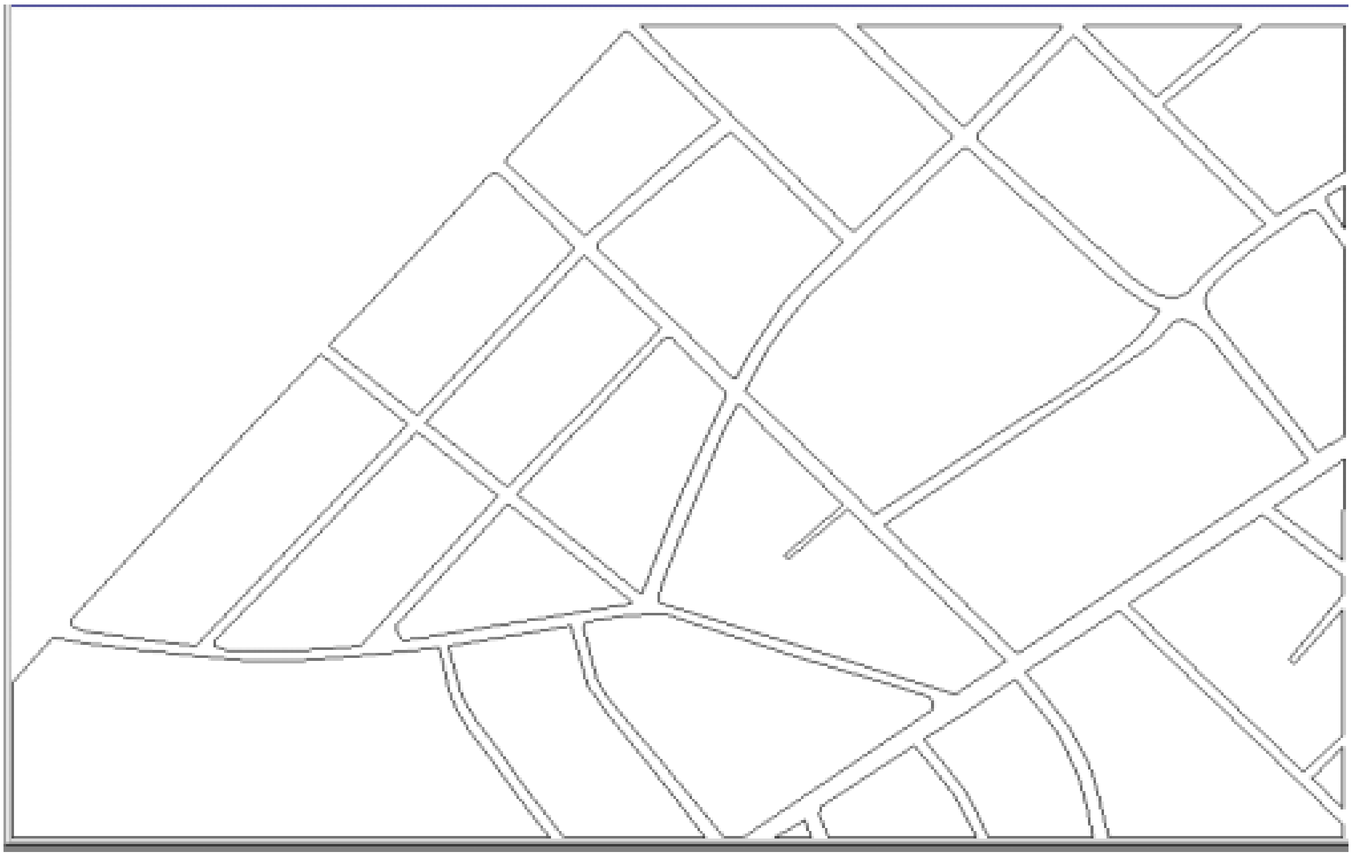

Map and Database Interaction
South America
Attributes of South America
Shape
Country
Population
Polygon Argentina 33796870
Polygon Bolivia 7648315
Polygon Brazil 151525400
Polygon Chile 13772710
Polygon Colombia 34414590



Geometric Classes of Data

DATA TYPES

VECTOR	RASTER
Point = Position, no area	**Point = 1 cell**
Line = Length, no width	**Line = Multiple cells joined at edges or corners, usually with only 1 or 2 neighbors**
Polygon = Area and perimeter	**Polygon = Group of contiguous cells joined at edges or corners**



VECTOR STRUCTURE

Advantages

- ❑ Good representation of the landscape being mapped
- ❑ Topology can be completely described, including network linkages
- ❑ Great looking graphics ("Looks like a map is supposed to")
- ❑ Generalization of the graphics is possible while still maintaining the great look ("What the map reader doesn't know won't hurt them")

RASTER STRUCTURE

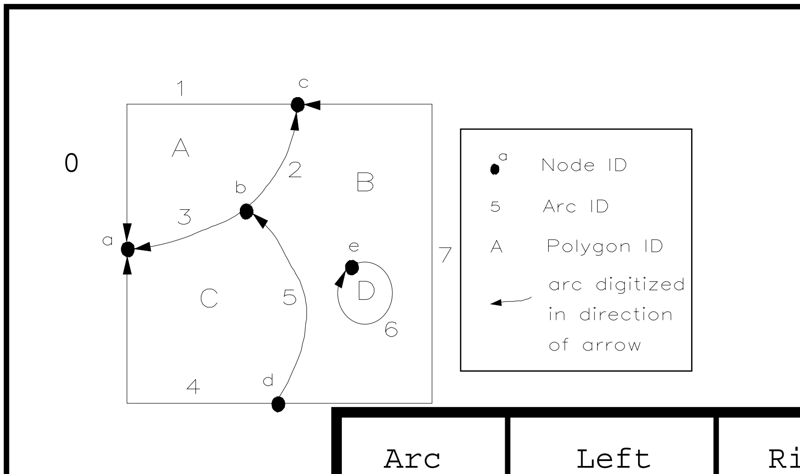
Advantages

- ❑ Overlaying maps is easy and "perfect" (i.e. no possibility of sliver polygons developing since all raster cell borders are coincident
- ❑ Integration of remotely sensed imagery (satellite images or scanned airphotos) is straight-forward
- ❑ A huge variety of complex spatial analyses are supported
- ❑ Software is generally cheaper and easier to learn compared to vector GISs

TOPOLOGY

Geometrical relationships between spatial objects (Points, Lines, and Areas), such as adjacency, that are not altered by distortion, as long as the surface is not torn

Example of "Built" Topology (from Arc/Info)



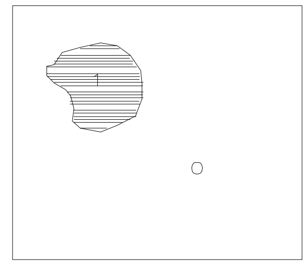
Arc ID	Left Poly	Right Poly	From Node	To Node
1	A	0	c	a
2	A	0	b	c
3	C	A	b	a
4	0	C	d	a
5	C	B	d	b
6	B	D	e	e
	B	0	d	c

Polygon ID	Number of arcs	List of arcs
A	3	-1,-2,3
B	4	2,-7,5,0,-6
C	3	-3,-5,4
D	1	6

Vector GIS ATTRIBUTE DATABASE

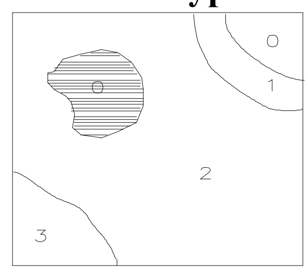
ID	Name	Quality	. . .
0	N/A		
1	Fir Lake	High	

Lakes



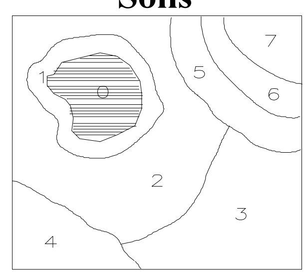
ID	Species	Size	. . .
0	N/A		
1	Jack Pine	Pole	
2	Spruce	Sapling	
3	Jack Pine	Sapling	

Forest Types



ID	Type	Depth	. . .
0	N/A		
1	B		
2	A		
3	B		
4	C		
5	C		
6	A		
7	R		

Soils



Type	Drainage	. . .
A	Fair	
B	Poor	
C	Good	
R	Rock	

Related Table "Type" is KEY FIELD

ENTITY RELATIONSHIPS

Point - Point	**Is nearest to ...**
	Interacts with ...
Point - Line	**Is on ...**
	Is nearest to ...
Point - Area	**Is within ...**
	Is adjacent to ...
Line - Line	**Intersects ...**
	Is upstream of ...
Line - Area	**Crosses ...**
	Is contained within ...
	Is nearest to ...
Area - Area	**Is adjacent to ...**
	Overlaps ...
	Is enclosed by ...

A Classification of GIS Functions

❑ **Analysis of Spatial and Attribute Data**

- **Non-spatial analyses**

  Attribute query and display
  Map retrieval and display
  Attribute classification
  Map measurements (distance, direction, area, etc.)

- **Spatial analyses**

  Overlay operations

  Neighborhood functions

  Distance and Connectivity functions
    Contiguity measures
    Proximity analysis
    Network analysis
    Spread functions
    Seek operands
    Intervisibility analysis
    Solar illumination calculation
    Perspective view

  Search operations
    Line-in-polygon; Point-in-polygon
    Topographic functions
    Thiessen polygons
    Interpolation
    Contour generation

This classification has been adapted from:

Aronoff, Stan. 1989. Geographic Information Systems: A Management Approach. Ottawa, Ontario, Canada: WDL Publications. 294p.

A Classification of GIS Functions

- **Maintenance of Attribute Data**

    Format conversions
    Database error checking
    Database editing

- **Maintenance of Spatial Data**

    Format conversions
    Geometric transformations
    Projection conversions
    Conflation
    Edge matching
    Editing of graphic elements
    Line coordinate thinning

- **Output functions**

    Map annotation
    Text labels
    Texture patterns and line styles
    Graphic symbols
    Plotting
    Printing (laser printers, color inkjet printers, etc.)

This classification has been adapted from:

Aronoff, Stan. 1989. Geographic Information Systems: A Management Approach. Ottawa, Ontario, Canada: WDL Publications. 294p.

Spatial Analyses

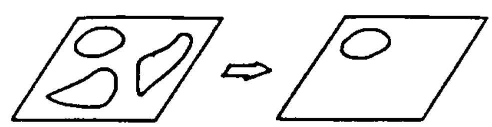
Basic Functional Classes

- ❑ **Reclassifying Maps** — *Vector and Raster*
- ❑ **Overlaying Maps**
- ❑ **Measuring Distance and Connectivity**
- ❑ **Characterizing Neighborhoods**

Position

Vector and Raster

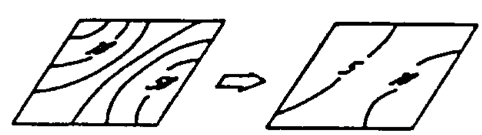
"only those in the NW"



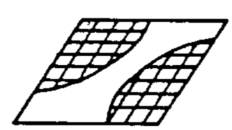
Value

Vector and Raster

"change feet to meters"



"elevations between 20 & 40 feet"

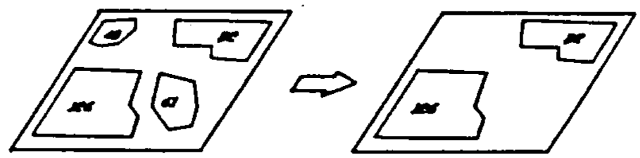


RECLASSIFYING MAPS

Size

Vector and Raster

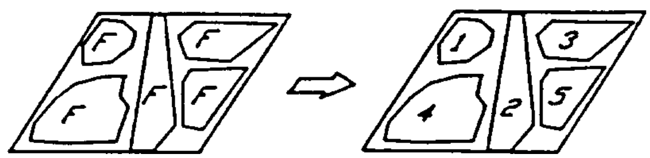
"larger than 80 acres"



Contiguity

Raster Only

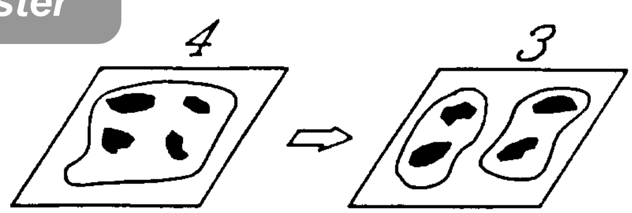
"work with individual members rathers than the class as a whole"



Shape

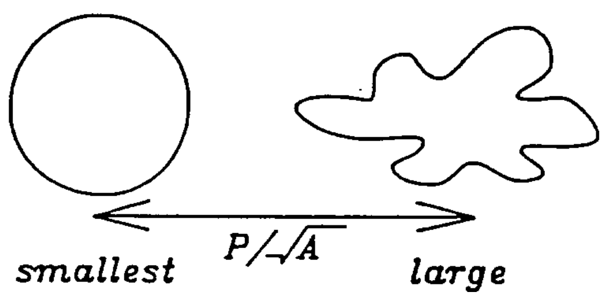
Vector and Raster

- Spatial Integrity



[# Holes – (# Fragments – 1)]

- Boundary Configuration



SPATIAL ANALYSES

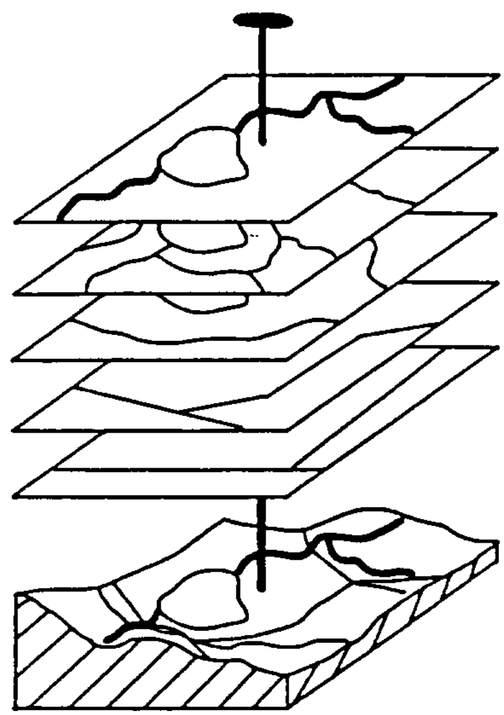
Basic Functional Classes

- ❑ Reclassifying Maps
- ❑ **Overlaying Maps** — *Vector and Raster*
- ❑ Measuring Distance and Connectivity
- ❑ Characterizing Neighborhoods

Point by Point

Vector and Raster

"piercing – needle" approach



All locations in the coverage or grid are evaluated. The results extend to the spatial limits of the input maps.

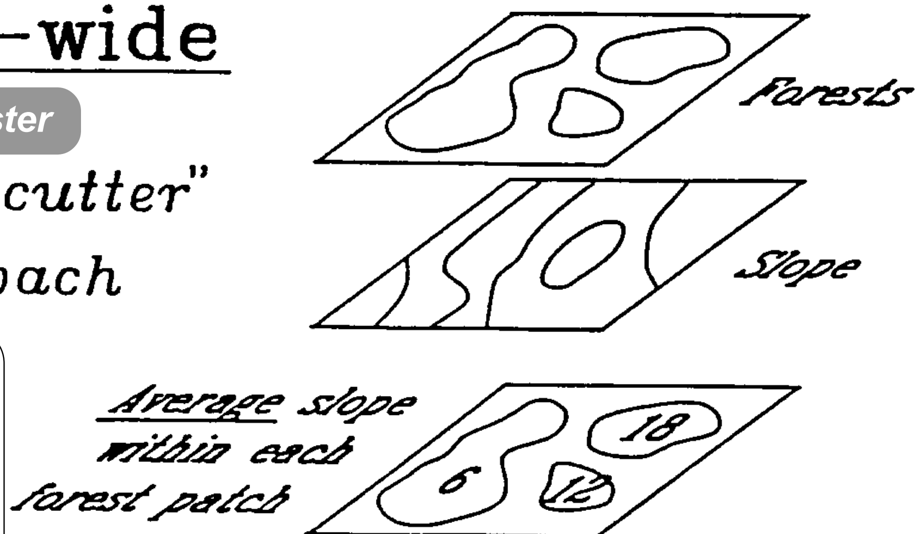
OVERLAYING MAPS

Region-wide

Vector and Raster

"cookie-cutter" approach

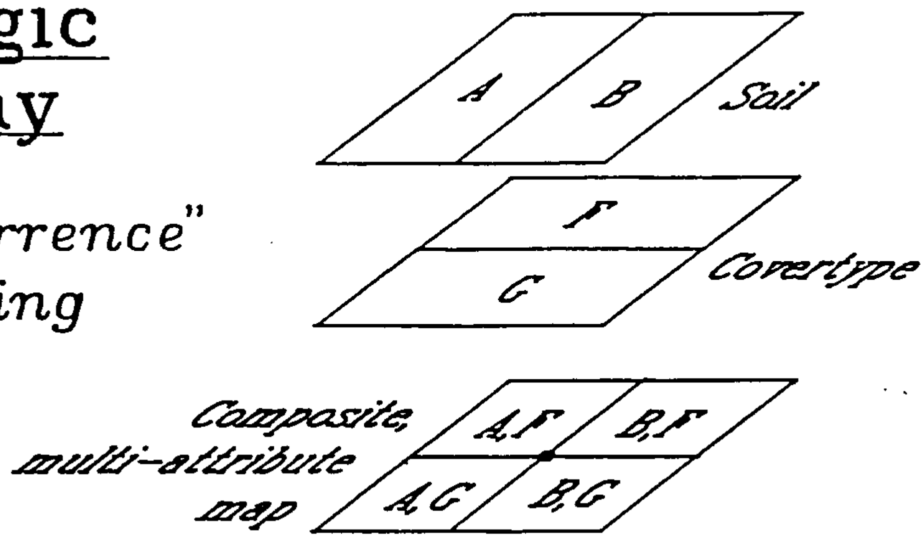
All locations in the coverage or grid are not necessarily evaluated. The results are constrained to the spatial nature of the reference map.



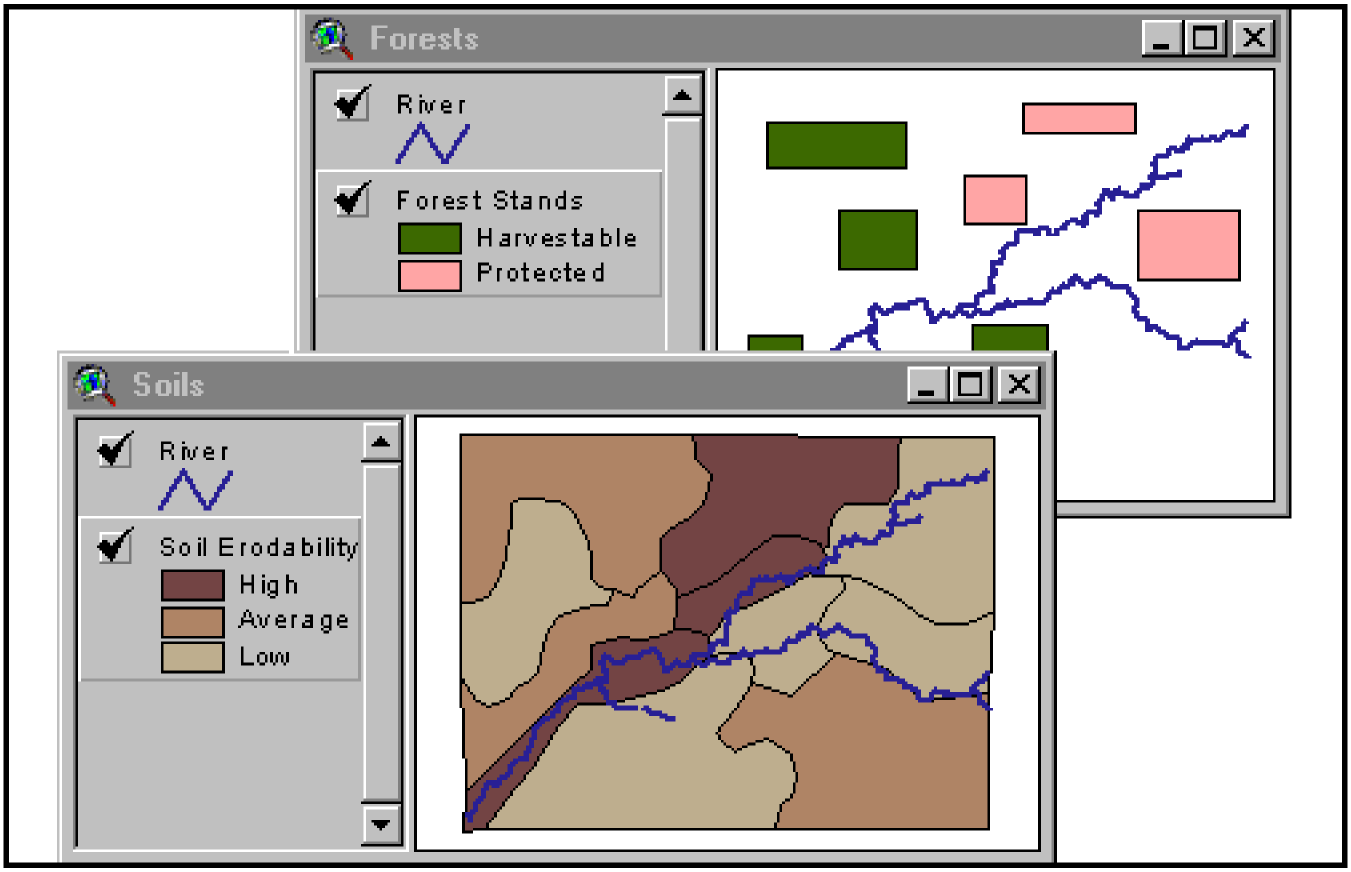
Vector Only

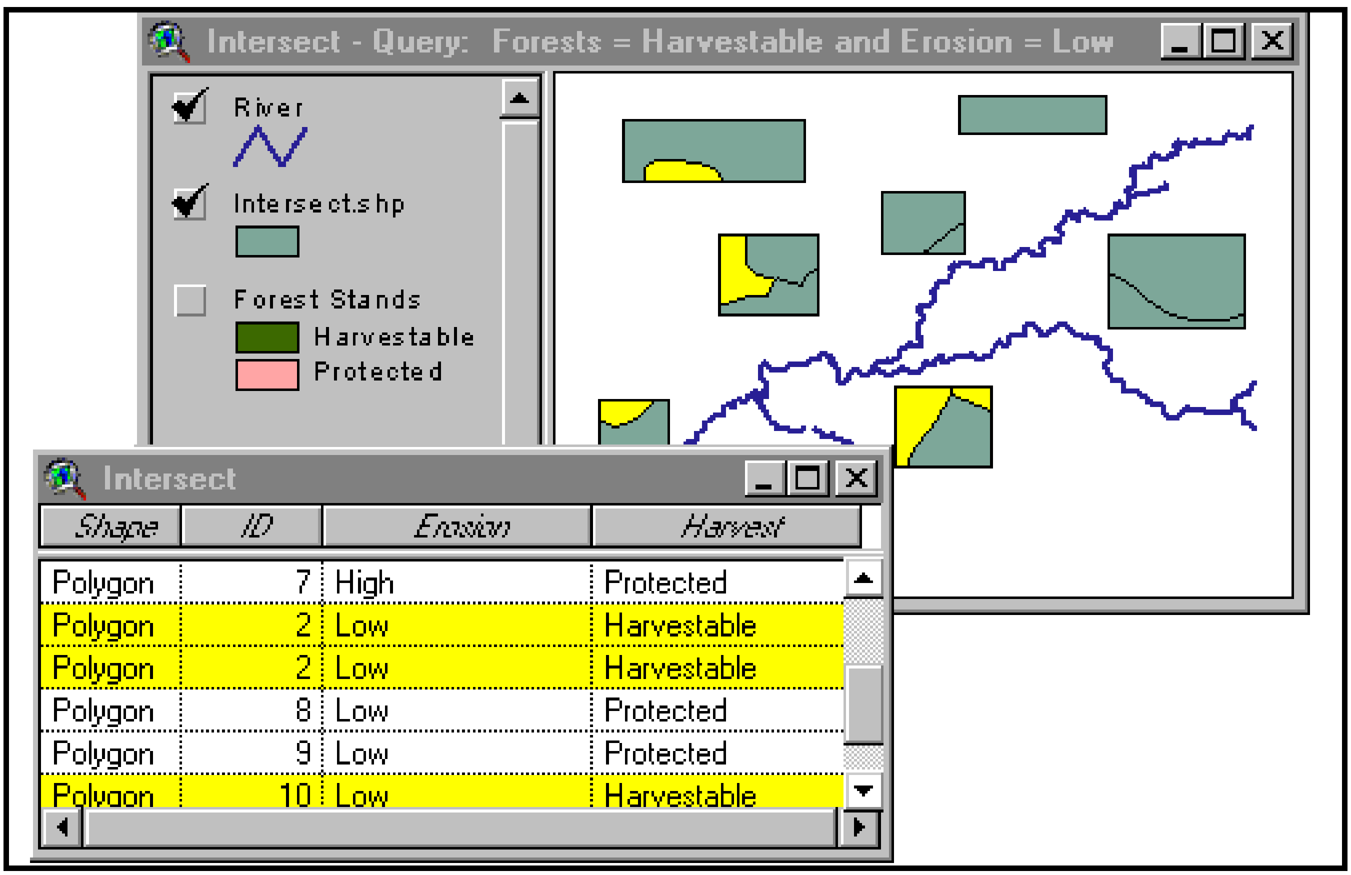
Topologic Overlay

"co-occurrence" mapping



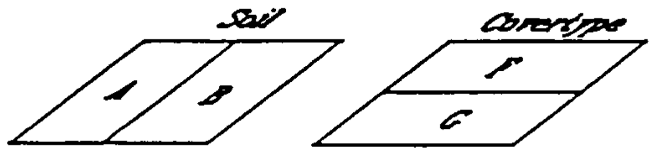
Note the new NODE - topologically correct areas were created


Forests
River
Forest Stands
Harvestable
Protected
Soils
River
Soil Erodability
High
Average
Low


Intersect - Query: Forests = Harvestable and Erosion = Low
River
Intersect.shp
Forest Stands
Harvestable
Protected
Intersect
Shape | ID | Erosion | Harvest
Polygon | 7 | High | Protected
Polygon | 2 | Low | Harvestable
Polygon | 2 | Low | Harvestable
Polygon | 8 | Low | Protected
Polygon | 9 | Low | Protected
Polygon | 10 | Low | Harvestable

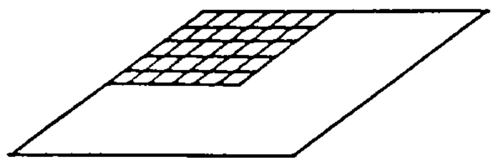
OVERLAYING MAPS

Boolean Overlay

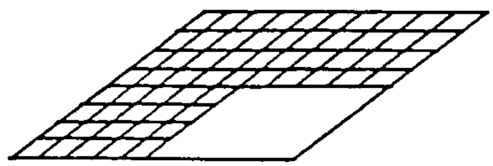


Vector and Raster

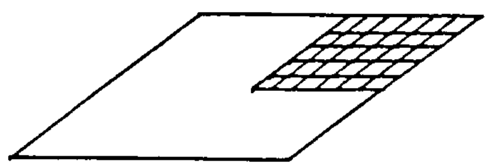
- Intersection
  "Forest AND Soil A"



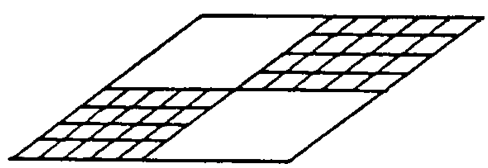
- Union
  "Forest OR Soil A"



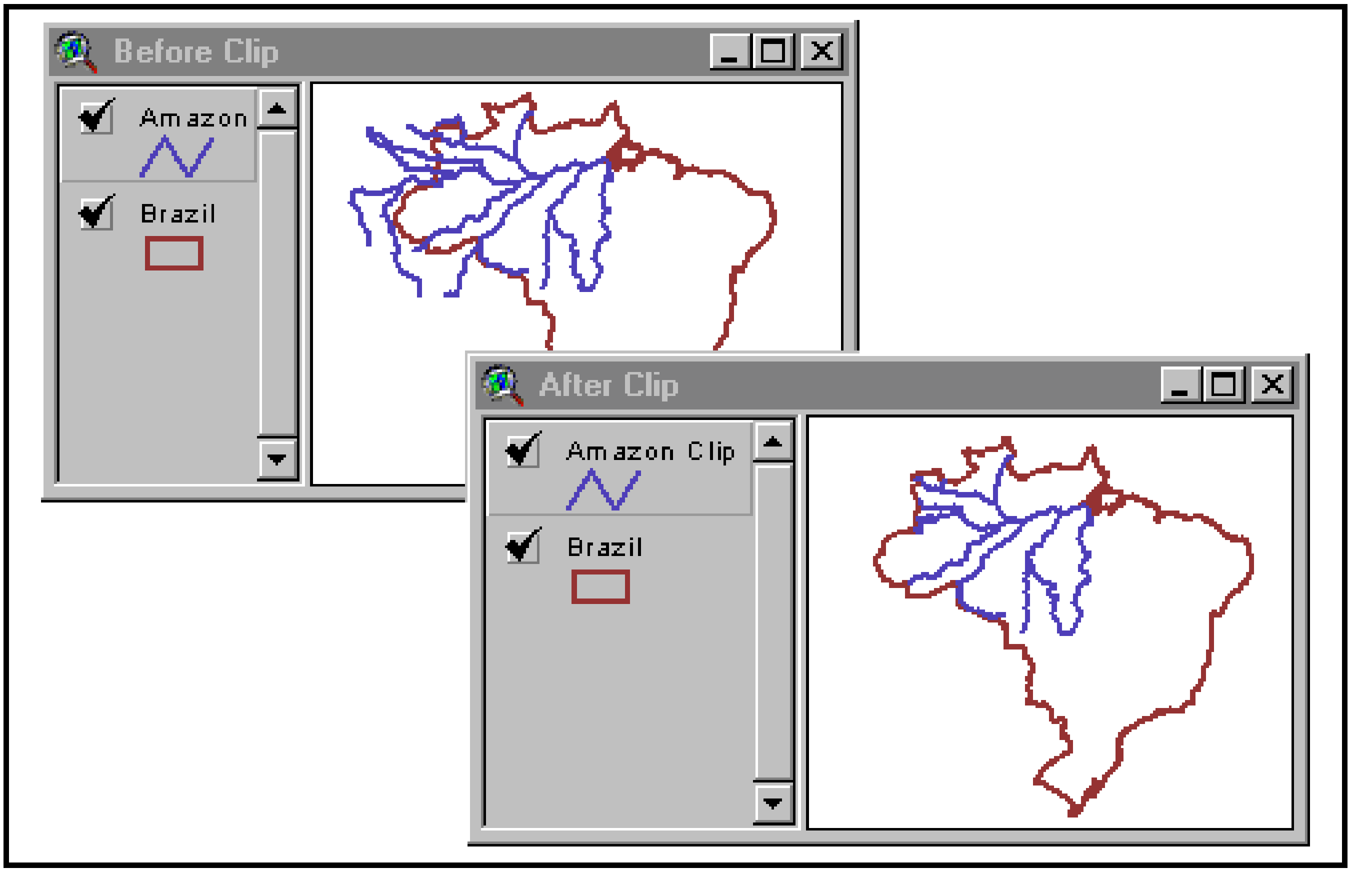
- Negate
  "Forest, but NOT on Soil A"



- Exclusive Or
  "Forest XOR Soil A"



Note: Most relational database management systems support a "SWAP" function which selects the *currently unselected* items in the database. In the example above, the "SWAP" function would return the white areas after the hatched areas had initially been selected.


Before Clip
Amazon
Brazil
After Clip
Amazon Clip
Brazil

SPATIAL ANALYSES

Basic Functional Classes

- ❑ Reclassifying Maps
- ❑ Overlaying Maps
- ❑ Measuring Distance and Connectivity
- ❑ Characterizing Neighborhoods

DISTANCE MEASURES

Point to Point

Vector and Raster

"How far is it from A to B?"

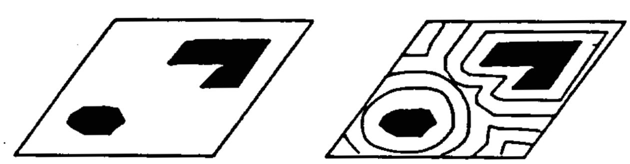
USEFUL, BUT LIMITED

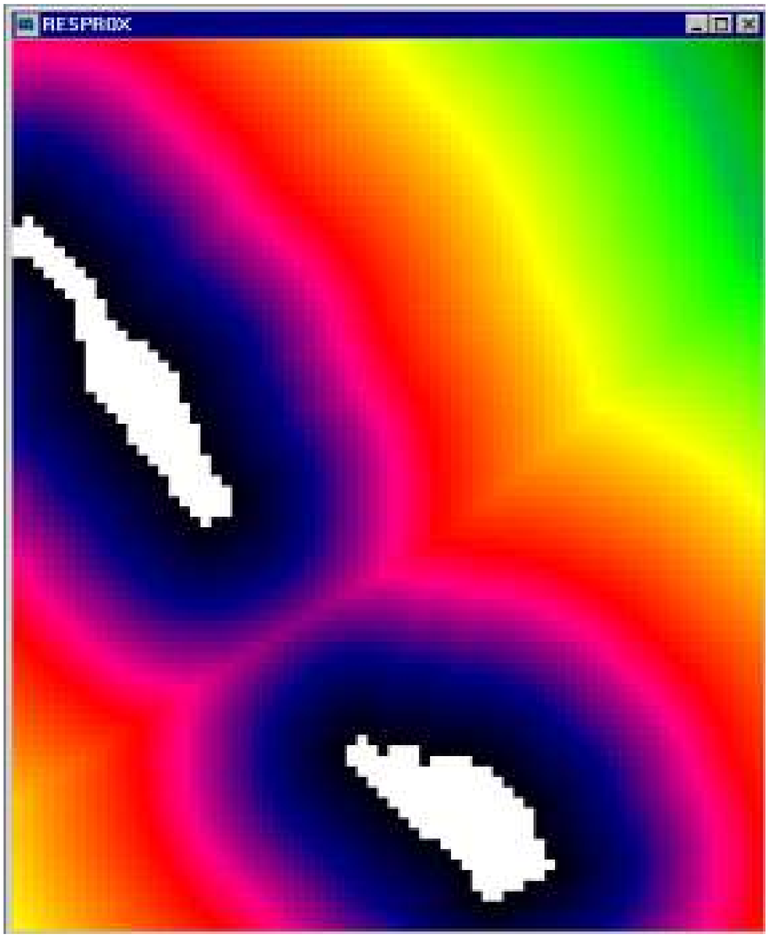
Proximity

Raster Only

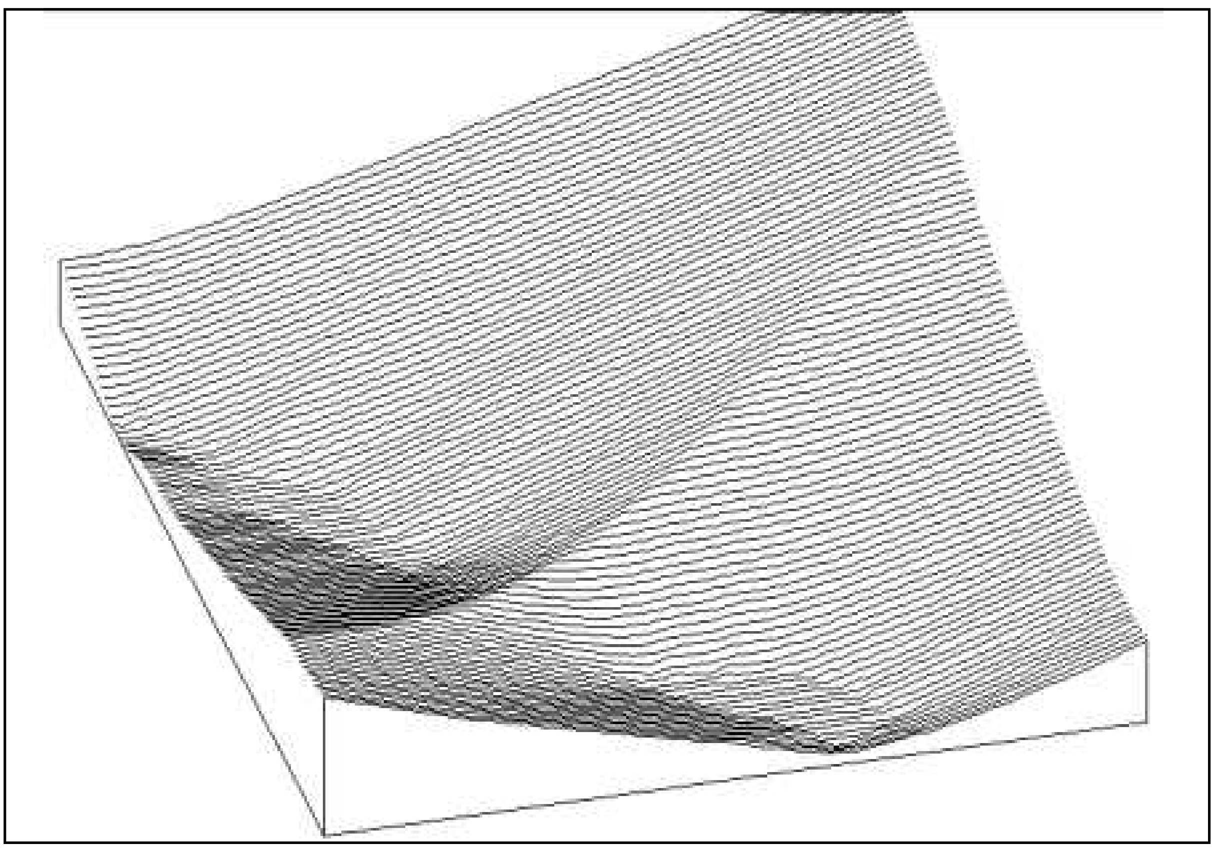
"How far from the forest is every location on the map?"

POWERFUL AND VERY DIFFICULT TO DO BY HAND





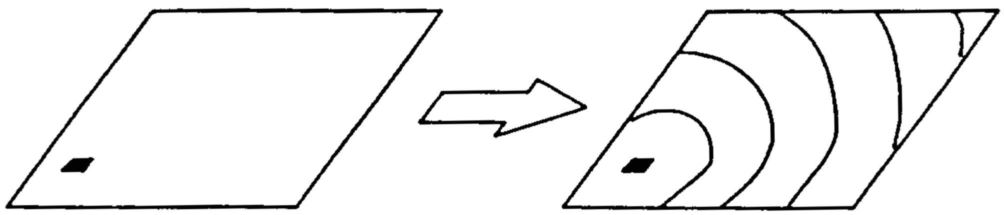
Simple (i.e. unweighted) PROXIMITY SURFACE



DISTANCE MEASURES

I Movement

Raster Only

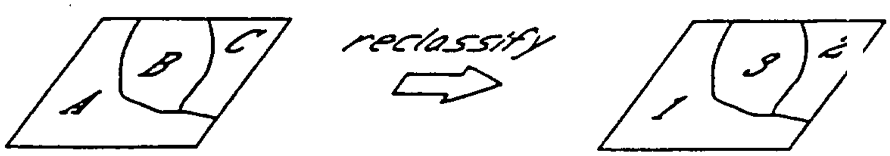


Start Location

Travel Time (Impedance = 0)

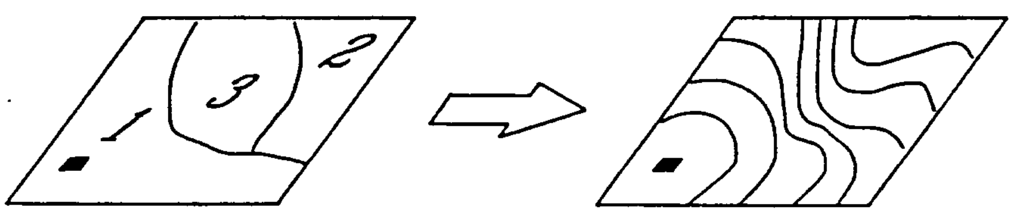
II Movement

Raster Only



A = gently sloping grassland
B = steeply sloping forest
C = gently sloping forest

1 = easy hiking
2 = harder hiking
3 = difficult hiking



Start Location

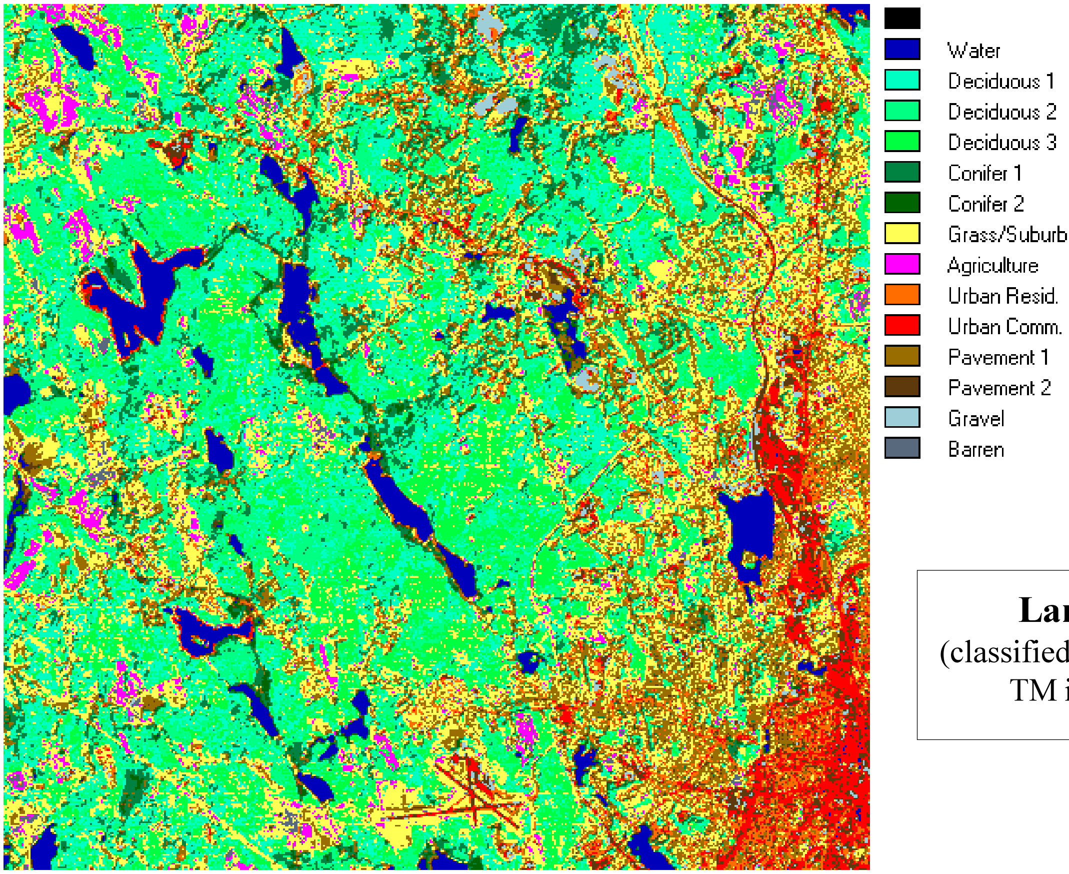
Travel Time (with variable impedances)

Least-Cost Pathway Analyses

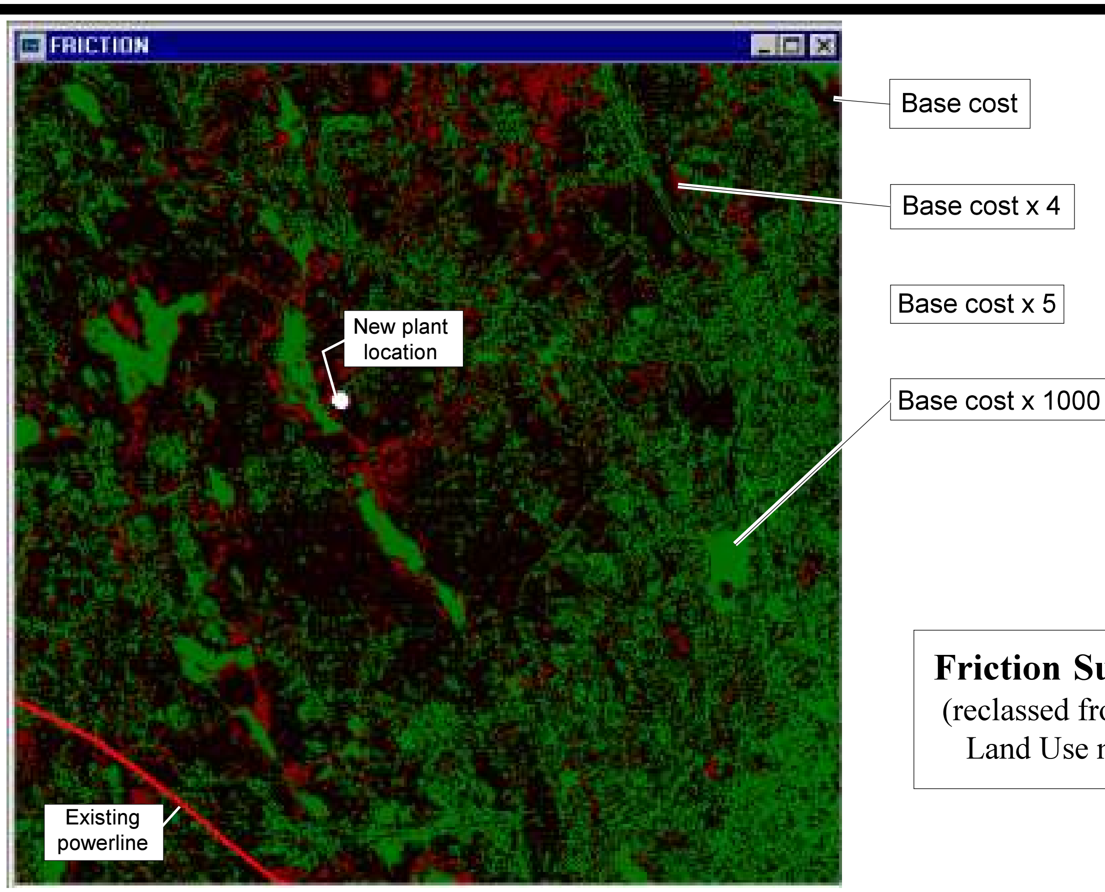
- ❑ **Create a FRICTION map from one or more existing coverages**

- ❑ **Create a COST SURFACE map by executing the PROXIMITY analysis *WEIGHTED BY* the FRICTION map**

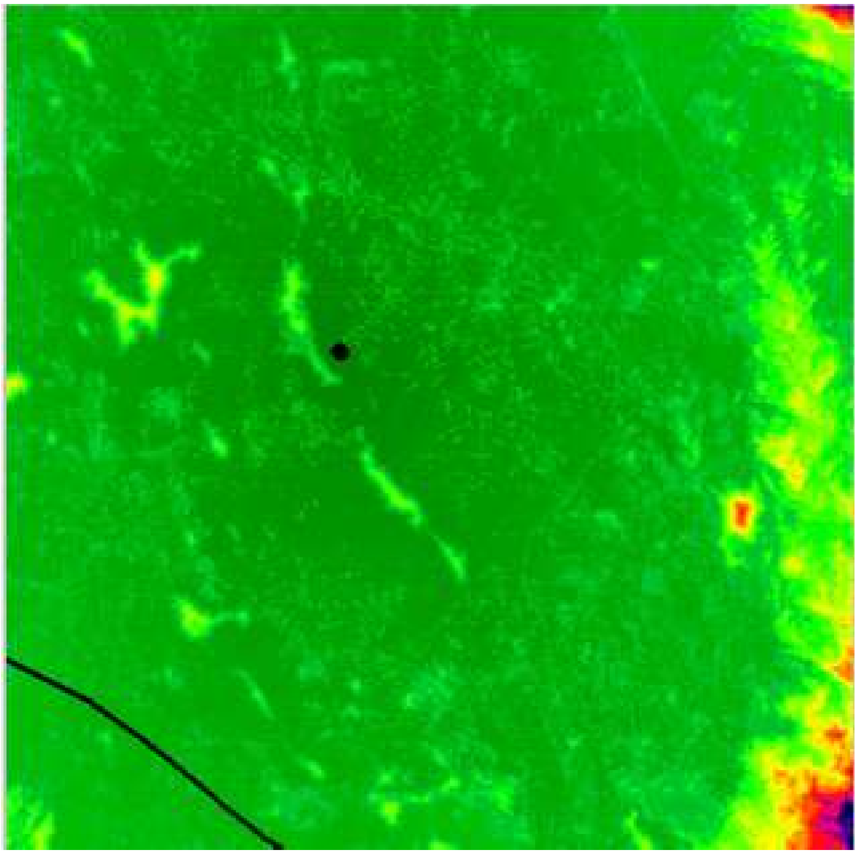
- ❑ **Execute the LEAST-COST PATHWAY module from one or more starter entities (points, lines or areas) to a destination. It will FIND the one (or more) routes that ACCUMULATE the least cost.**



Land Use
(classified from Landsat TM imagery)

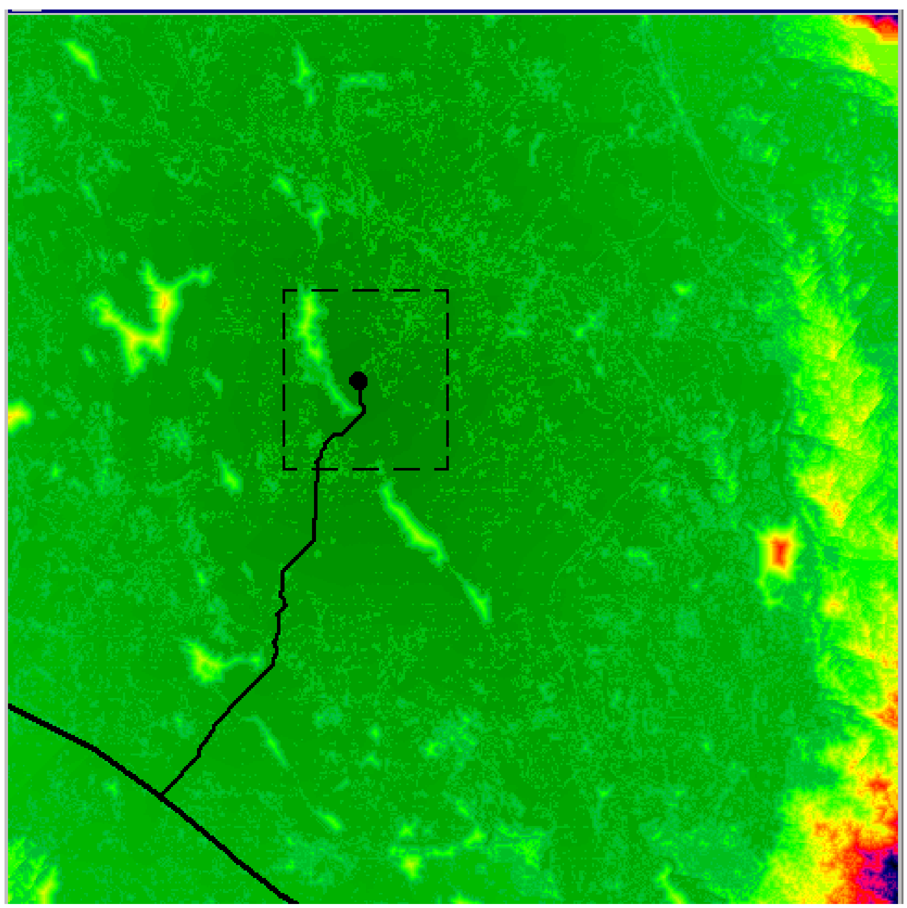


Friction Surface
(reclassed from the Land Use map)

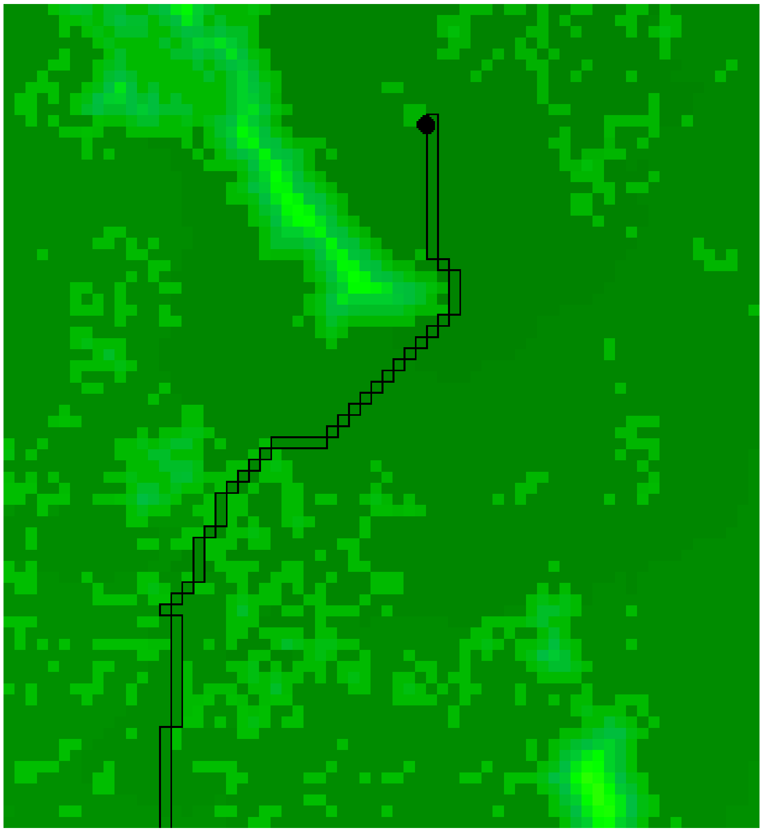


Cost Surface (Proximity x Friction)

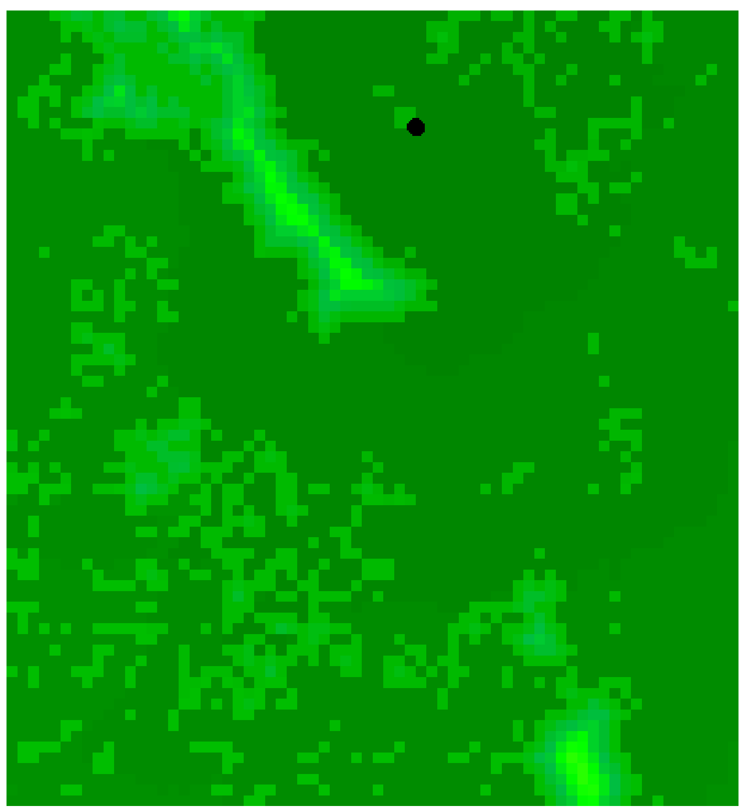
Least-Cost Pathway



Least-Cost Pathway



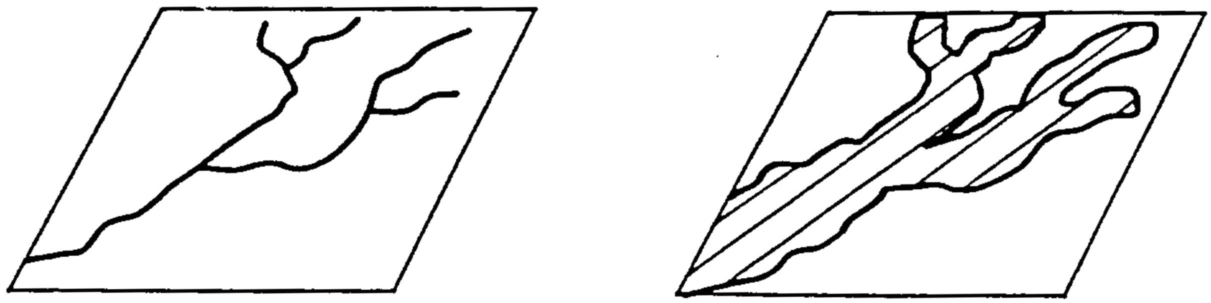
Least-Cost Pathway



CONNECTIVITY

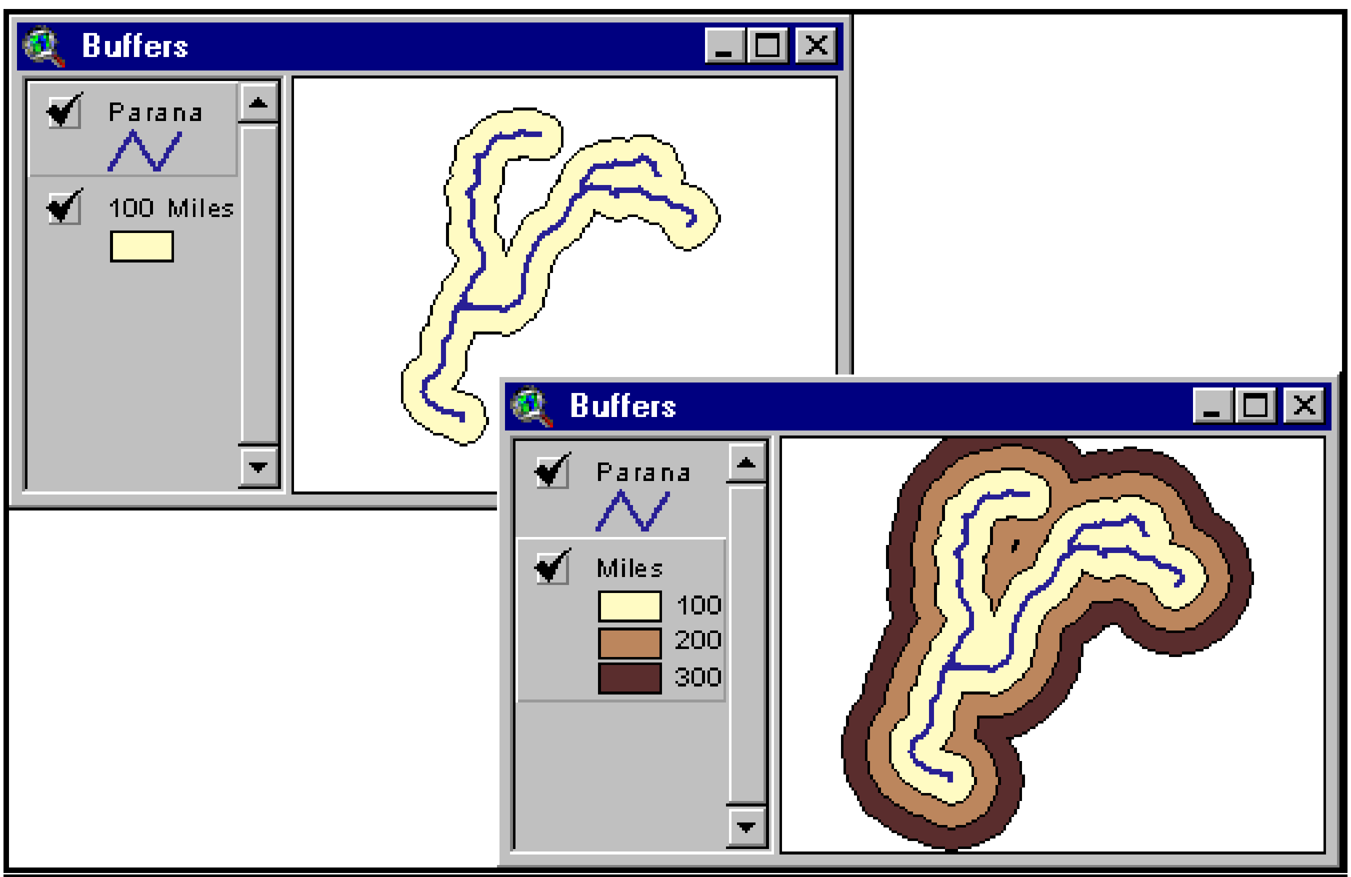
Buffering

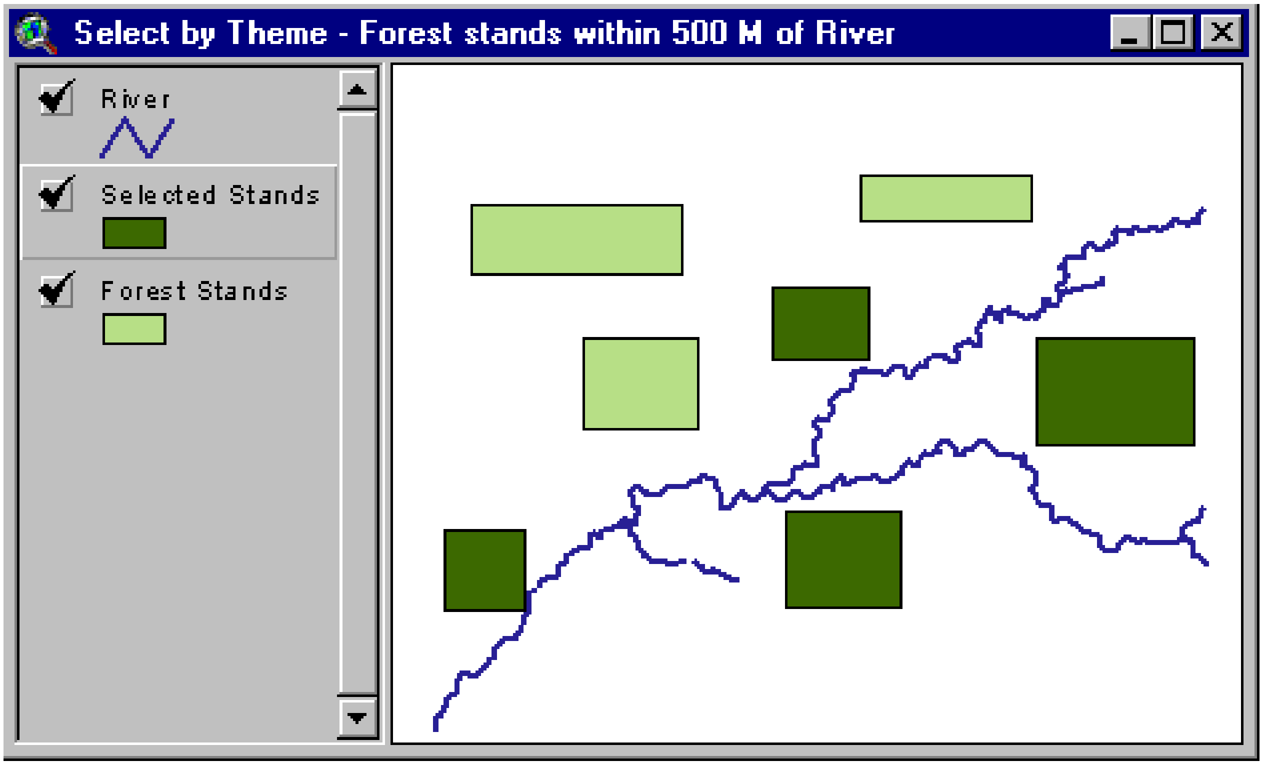
Vector and Raster

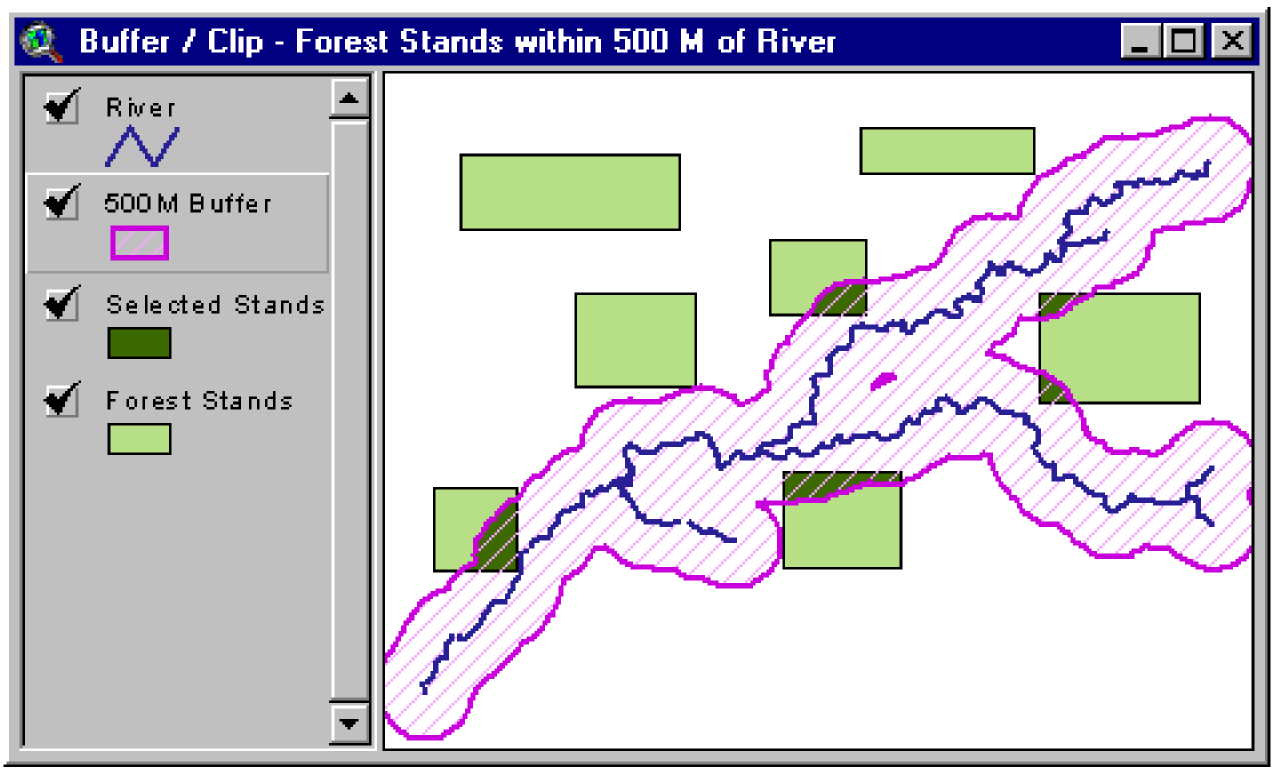


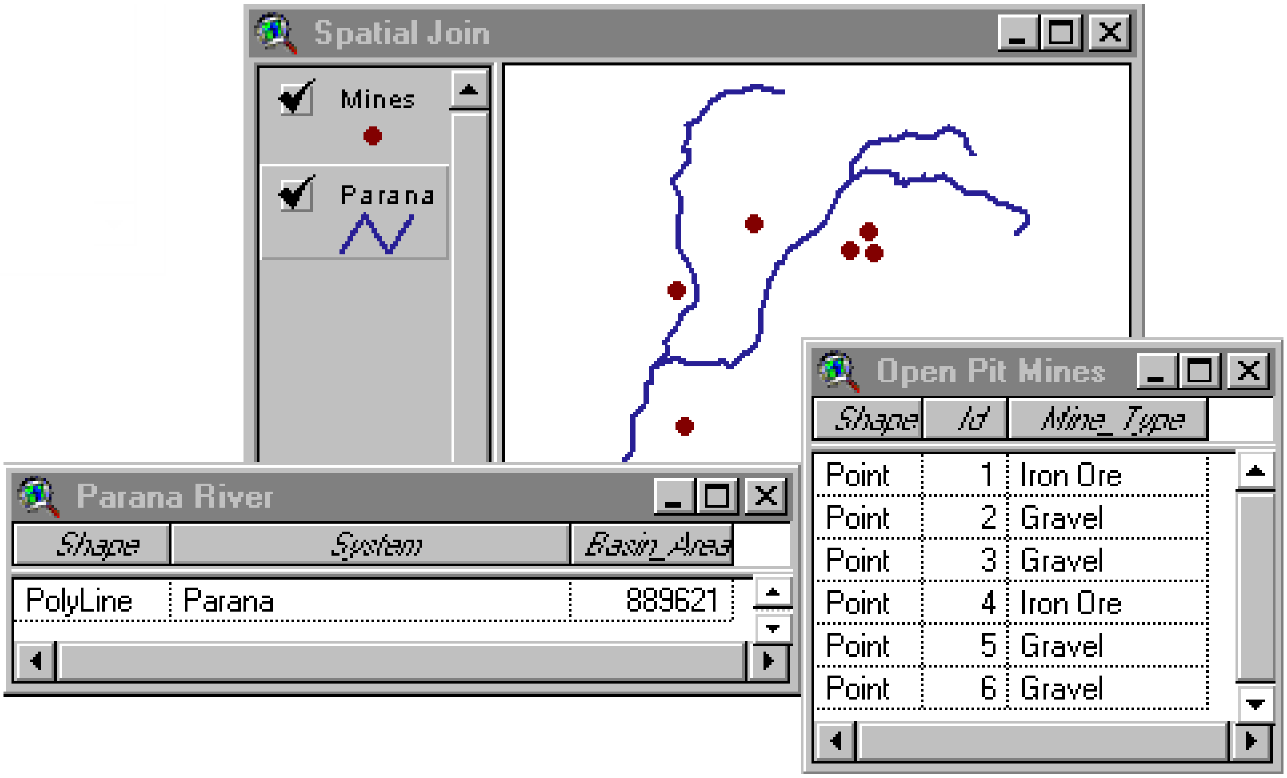
establish limited use zones

100 m 1st-order streams
200 m 2nd-order streams
500 m 3rd-order streams




Select by Theme - Forest stands within 500 M of River
River
Selected Stands
Forest Stands

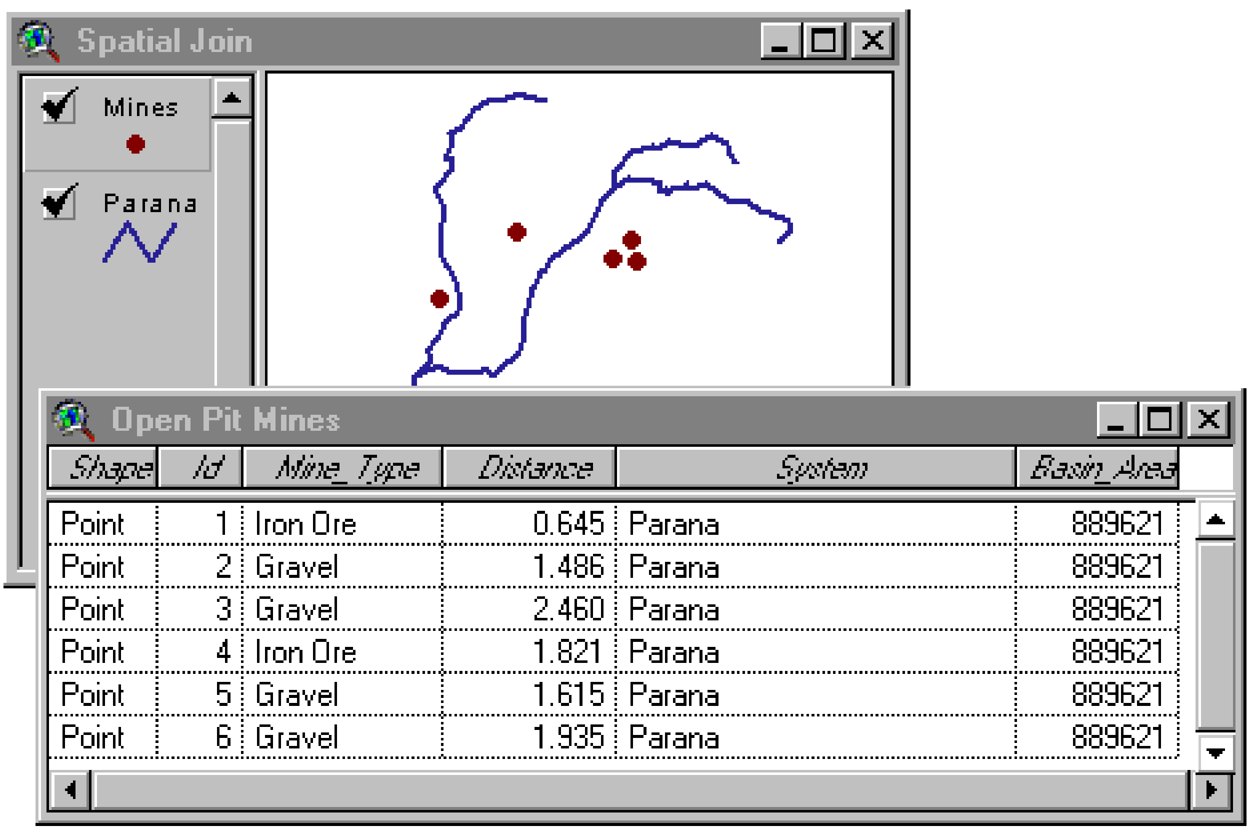

Buffer / Clip - Forest Stands within 500 M of River
River
500 M Buffer
Selected Stands
Forest Stands


Spatial Join
Mines
Parana
Parana River

Shape	System	Basin_Area
PolyLine	Parana	889621

Open Pit Mines

Shape	Id	Mine_Type
Point	1	Iron Ore
Point	2	Gravel
Point	3	Gravel
Point	4	Iron Ore
Point	5	Gravel
Point	6	Gravel


Spatial Join
Mines
Parana
Open Pit Mines

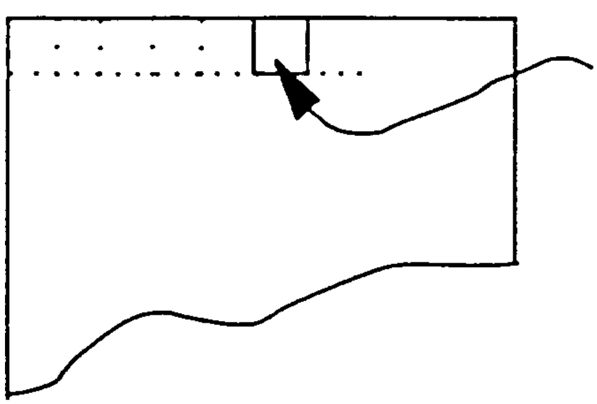
Shape	Id	Mine_Type	Distance	System	Basin_Area
Point	1	Iron Ore	0.645	Parana	889621
Point	2	Gravel	1.486	Parana	889621
Point	3	Gravel	2.460	Parana	889621
Point	4	Iron Ore	1.821	Parana	889621
Point	5	Gravel	1.615	Parana	889621
Point	6	Gravel	1.935	Parana	889621

SPATIAL ANALYSES

Basic Functional Classes

- ❑ **Reclassifying Maps**
- ❑ **Overlaying Maps**
- ❑ **Measuring Distance and Connectivity**
- ❑ **Characterizing Neighborhoods** *Raster Only*

CHARACTERIZING NEIGHBORHOODS



Neighborhood = User–Defined Area of Scrutiny

"Roving Window"

(e.g. ... per square mile; ... per hectare)

WINDOW OPERATIONS

Raster Only

Slope

Slope Aspect

Maximum, Minimum

Mean, Median, Mode

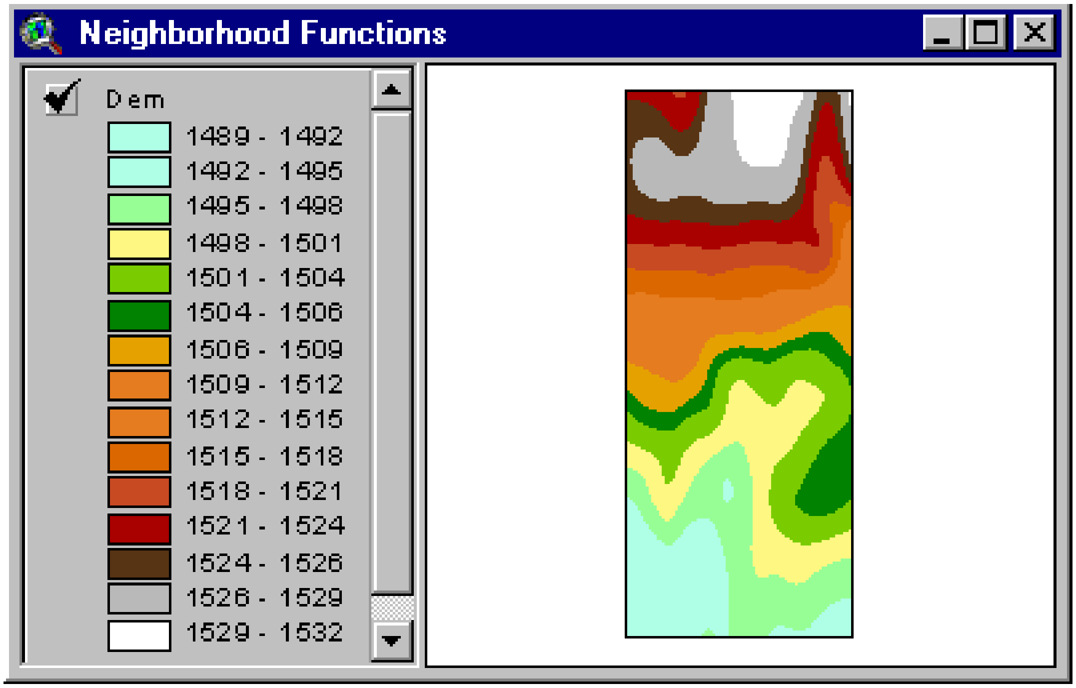
Standard Deviation

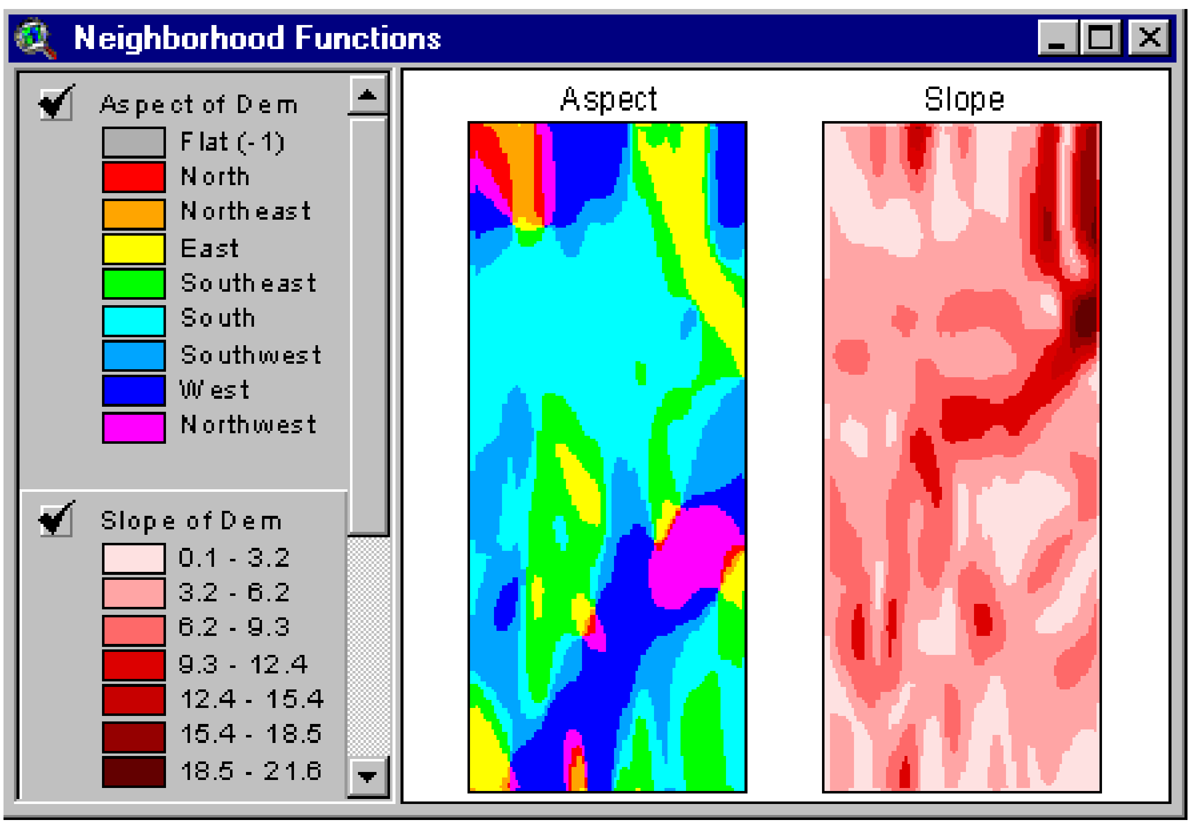
Majority, Minority

Total Count

Diversity

Large number of Spatial Pattern or Texture Indexes
(e.g. Dominance Index, Relative Richness, etc.)


Neighborhood Functions
Dem
1489 - 1492
1492 - 1495
1495 - 1498
1498 - 1501
1501 - 1504
1504 - 1506
1506 - 1509
1509 - 1512
1512 - 1515
1515 - 1518
1518 - 1521
1521 - 1524
1524 - 1526
1526 - 1529
1529 - 1532


Neighborhood Functions
Aspect of Dem
Flat (-1)
North
Northeast
East
Southeast
South
Southwest
West
Northwest
Slope of Dem
0.1 - 3.2
3.2 - 6.2
6.2 - 9.3
9.3 - 12.4
12.4 - 15.4
15.4 - 18.5
18.5 - 21.6
Aspect
Slope

Examples of Neighborhood Operations to Determine Spatial Pattern

Each of the following measures are calculated within a **3 x 3 pixel window** which systematically roves throught the data set. The outcome calculation is assigned to the center cell in the window (in the output file), then the window moves over one pixel along a row and recalculates a new value for that center-pixel location, etc.

Relative Richness = n / (nmax) x 100

where n = number of different classes present

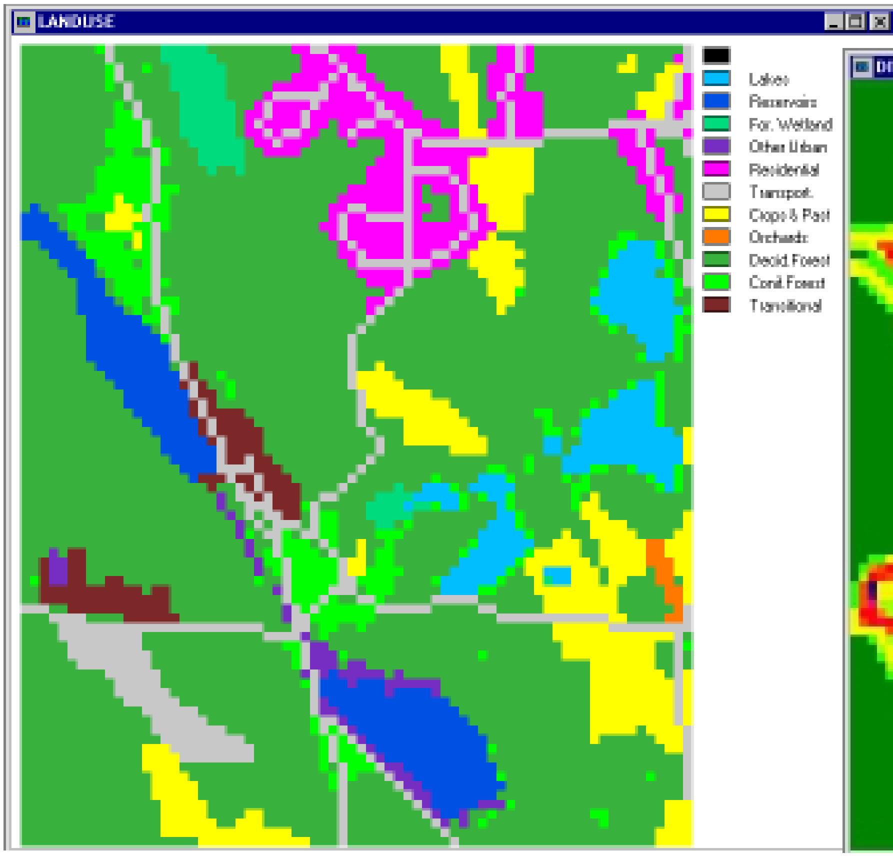
Diversity = -sum[(p) x ln(p)]

where sum = the sum over all classes; p = proportion of the footprint in each class; ln = natural logarithm

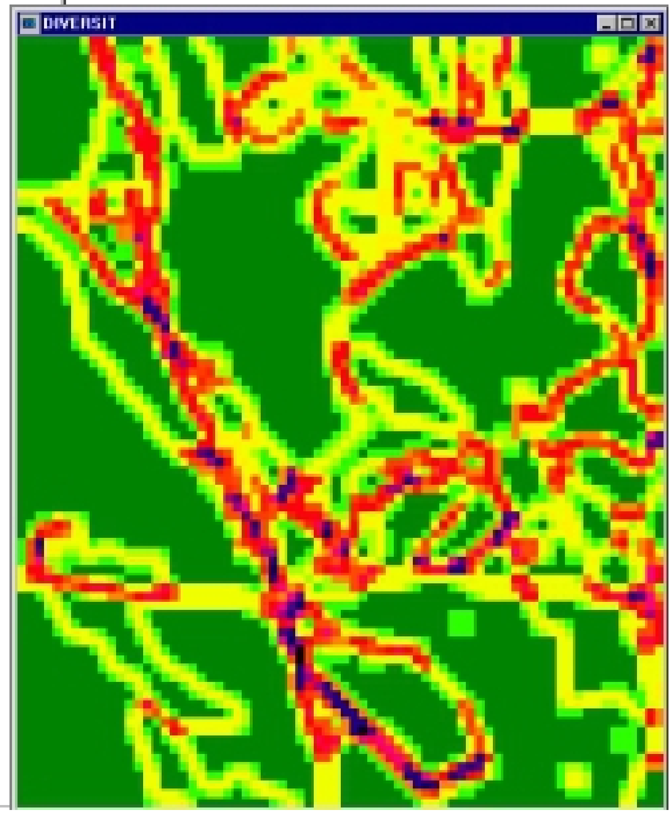
Dominance = Hmax - H

where H = Diversity; Hmax = maximum diversity = ln(n); n = number of different classes present; ln = natural logarithm

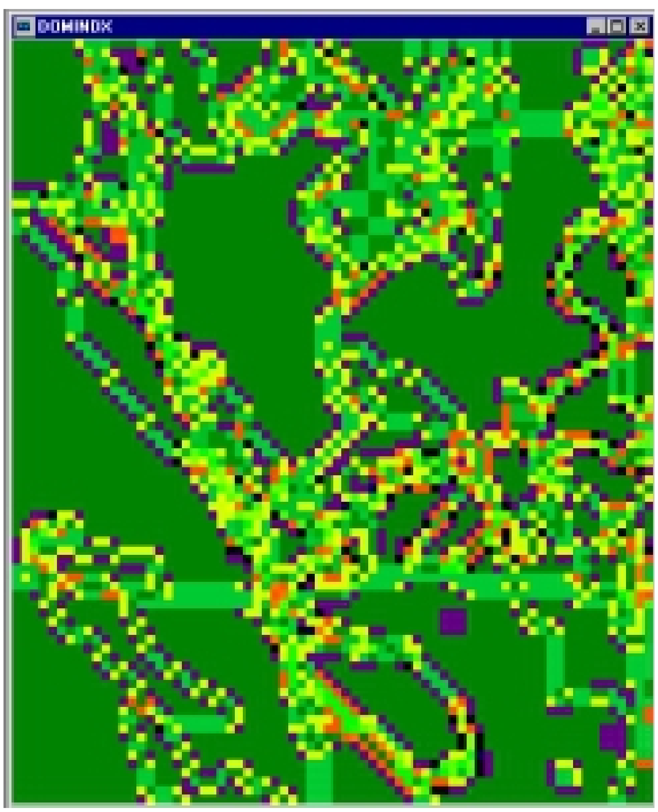
from: Turner, M.G. 1989. Landscape Ecology: The Effect of Pattern on Process, *Annu. Rev. Ecol. Syst.*, 20, 171-197.



Diversity



Dominance Index



Relative Richness